

IMAGE PROCESSING METHOD, IMAGE PROCESSING APPARATUS,
AND STORAGE MEDIUM

BACKGROUND OF THE INVENTION

5 Field of the Invention

The present invention relates to a technical field in which a color signal located within a first color reproduction gamut (or range) represented by a first color system is subjected to mapping conversion into a color signal located within a second color reproduction gamut represented by the first color system.

Related Background Art

In recent years, as a personal computer and a work station spread, DTP (desktop publishing) and CAD (computer-aided design) have come to be widely used. Thus, color reproduction technique by which a color represented on a monitor by the computer is actually reproduced by using a coloring agent becomes important. For example, in the DTP, a computer system which includes at least a color monitor and a color printer creates, edits and processes a color image on the color monitor, and then outputs the obtained color image by the color printer. Here, a user strongly wishes that the color image on the monitor sensuously and the printer output image are matched.

However, in the color reproduction technique, difficulty is attended so that the color image on the

monitor and the printer output image may be matched, because of the following reasons.

The color monitor represents the color image by generating light of a specific frequency with use of a 5 fluorescent body. On the other hand, the color printer absorbs light of a specific frequency by using ink or the like, and represents the color image based on remaining reflection light. Thus, since an image display form of the color monitor is different from an 10 image display form of the color printer, the color reproduction gamut of the color monitor is highly different from the color reproduction gamut of the color printer. Further, even in the color monitors, the color reproduction gamut is different among a 15 liquid crystal monitor, a CRT (cathode-ray tube) of electron-gun type, and a plasma monitor. Also, even in the color printers, the color reproduction gamut is different in accordance with difference of sheet quality, difference of ink usage quantity, and the 20 like. For this reason, it is impossible to completely match the color of the image on the color monitor with the color of the image output from the color printer colorimetrically. It is also impossible to completely match the colors of the images on the plural kinds of 25 sheets output from the plural kinds of color printers colorimetrically. Therefore, when a person perceives the displayed color image on each output medium, he

feels serious distinction about each output image.

Here, as technique to absorb perceivable distinction on the displayed color image and perceivably match the displayed images among the display media of which the reproduction gamuts are different from others, there is gamut mapping technique that one color reproduction gamut is mapped into another color reproduction gamut by using a uniform color system. As one example of the gamut mapping technique, there is the technique that, in the uniform color system, linear mapping is performed in a lightness-chroma dimension for each hue. According to this technique, a monitor color reproduction gamut as schematically shown in Fig. 27 is mapped into a printer color reproduction gamut as schematically indicated by the dotted line in Fig. 28.

However, the image which was corrected by the linear mapping and then output might be undesirable perceivably. Namely, the difference between the shape of the monitor color reproduction gamut and the shape of the printer color reproduction gamut causes unnaturalness.

Here, the difference between the shape of the monitor color reproduction gamut and the shape of the printer color reproduction gamut will be simply explained. For example, Fig. 29 schematically shows the monitor and printer color reproduction gamuts in a

green hue. Namely, in Fig. 29, the printer color reproduction gamut is indicated by the solid line, while the monitor color reproduction gamut is indicated by the dotted line. As apparent from Fig. 29, in the 5 green hue, the monitor color reproduction gamut is nonsimilar to the printer color reproduction gamut, and thus the shape of the monitor color reproduction gamut is quite different from the shape of the printer color reproduction gamut. Then, Fig. 30 schematically shows 10 the monitor and printer color reproduction gamuts in a red hue. In Fig. 30, the monitor color reproduction gamut is indicated by the solid line, while the printer color reproduction gamut is indicated by the dotted line. As apparent from Fig. 30, in the red hue, the 15 shape of the monitor color reproduction gamut is relatively similar to the shape of the printer color reproduction gamut.

In order to solve the above problem, nonlinear gamut mapping to keep chroma in the low-chroma part and 20 lightness in the intermediate-lightness part and also absorb the difference between the shape of the monitor color reproduction gamut and the shape of the printer color reproduction gamut is efficient.

As the nonlinear gamut mapping, a method of 25 superposing one- to three-dimensional mapping has been proposed.

However, in this nonlinear gamut mapping, there is

room of improvement in the point of gradation. Namely, in case of superposing the one- to three-dimensional mapping according to the conventional gamut mapping method, each mapping is different from others because 5 of chromaticity, hue and the like of the mapping-target color. Thus, even if there is no problem in the individual mapping either, a problem might occur in the gradation as a result of superposing each mapping.

Here, it should be noted that the term "gradation" 10 is used for the meaning of a proper change rate in a case where color changes according to a certain rule. Further, the operation to keep the gradation corresponds to the operation to properly keep the change rate. Next, Figs. 31A and 31B will be briefly 15 explained. In a case where a proper change rate has varied greatly as shown by the part enclosed with the circle in Fig. 31A, in general, such the variation frequently causes a pseudo contour and the like though it is dependent on conditions such as hue, chroma and 20 the like. On the other hand, in a case where a proper change rate can be kept as shown in Fig. 31B, a perceivable problem does not occur easily.

SUMMARY OF THE INVENTION

25 An object of the present invention is to absorb a difference in shapes of color reproduction gamuts, provide mapping conversion as keeping gradation,

suppress a pseudo contour in an output image, and obtain a high-quality output image.

In order to achieve the above object, the present invention provides an image processing method by which

5 a color signal located within a first color reproduction gamut represented by a first color system is subjected to mapping conversion into a color signal located within a second color reproduction gamut represented by the first color system, wherein

10 a locus of a change of color in the first color reproduction gamut is represented by a curve, mapping is performed to the curve, and the mapping conversion is performed on the basis of relation of the curves before and after the mapping.

15 Other objects and features of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings.

20 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a system structure of a color signal conversion device according to the first embodiment of the present invention;

25 Fig. 2 is a block diagram showing a structure of the color signal conversion device according to the first embodiment;

Fig. 3 is a flow chart showing a mapping operation

of a color gamut mapping device 207 in the first embodiment;

5 Fig. 4 is a schematic diagram showing loci of a surface sample point before and after the mapping on a green face;

Fig. 5 is a flow chart showing a mapping operation in a step 303 of Fig. 3 in the second embodiment of the present invention;

10 Fig. 6 is a flow chart showing a mapping operation in a step 502 of Fig. 5 in the second embodiment;

Fig. 7 is a schematic diagram showing spatial relation of color M and color Bm;

15 Fig. 8 is a diagram showing an example of a chroma input/output function for achieving nonlinear mapping of a chroma component;

Fig. 9 is a diagram showing an example of a lightness input/output function for achieving nonlinear mapping of a lightness component;

20 Fig. 10 is a schematic diagram showing a state of mapping on a green face;

Fig. 11 is a flow chart showing a mapping operation in a step 504 of Fig. 5 in the second embodiment;

25 Fig. 12 is a schematic diagram showing spatial relations of respective lines used in steps 1101 to 1106;

Figs. 13A and 13B are diagrams showing an example

of the lightness input/output function for achieving the nonlinear mapping of the lightness component;

Fig. 14 is a schematic diagram showing a state of mapping until a lightness adjustment mapping operation 5 in the step 504, on the green face;

Fig. 15 is a flow chart showing the mapping operation in the step 504 of Fig. 5 in the second embodiment;

Fig. 16 is a schematic diagram showing spatial 10 relations of respective colors obtained in steps 1501 to 1504;

Figs. 17A and 17B are diagrams showing an example of the chroma input/output function for achieving the nonlinear mapping of the chroma component;

Fig. 18 is a schematic diagram showing a state of 15 the mapping on the green face;

Fig. 19 is a schematic diagram showing surface gradation lines before the mapping;

Fig. 20 is a schematic diagram showing the surface 20 gradation lines after the mapping;

Fig. 21 is a schematic diagram showing internal gradation lines before the mapping;

Fig. 22 is a schematic diagram showing the internal gradation lines after the mapping;

Fig. 23 is a schematic diagram showing the 25 internal gradation lines before the mapping;

Fig. 24 is a schematic diagram showing the

internal gradation lines after the mapping;

Fig. 25 is a table showing values capable of being taken as R, G and B values;

Fig. 26 is a schematic diagram showing distribution of surface sample points and internal sample points on a sectional plane in an RGB color space;

Fig. 27 is a schematic diagram showing a monitor color reproduction gamut in a green hue;

Fig. 28 is a schematic diagram showing an example of gamut mapping;

Fig. 29 is a schematic diagram showing a monitor color reproduction gamut and a printer color reproduction gamut in the green hue;

Fig. 30 is a schematic diagram showing a monitor color reproduction gamut and a printer color reproduction gamut in the red hue; and

Figs. 31A and 31B are schematic diagrams for explaining gradation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
(First Embodiment)

Fig. 1 is a block diagram showing a system structure of a color signal conversion device according to the first embodiment.

In Fig. 1, numeral 101 denotes a CPU (central processing unit), numeral 102 denotes a main memory,

numeral 103 denotes a SCSI (small computer system interface), numeral 104 denotes a network I/F (interface), numeral 105 denotes an HDD (hard disk drive), numeral 106 denotes a graphic accelerator,
5 numeral 107 denotes a color monitor, numeral 108 denotes a color signal conversion device, numeral 109 denotes a color printer, numeral 110 denotes a keyboard/mouse controller, numeral 111 denotes a keyboard, numeral 112 denotes a mouse, numeral 113
10 denotes a LAN (local area network), and numeral 114 denotes a PCI (peripheral component interface) bus.

Image data stored in the HDD 105 is transferred to the main memory 102 through the SCSI 103 and the PCI bus 114, in response to an instruction from the CPU 101. Further, image data stored in a server connected to the LAN 113 or image data on the Internet is transferred to the main memory 102 through the network I/F 104 and the PCI bus 114, in response to an instruction from the CPU 101.

20 The image data stored in the main memory 102 is transferred to the graphic accelerator 106 through the PCI bus 114 in response to an instruction from the CPU 101. The transferred image data is D/A (digital-to-analog) converted by the graphic accelerator 106, the 25 obtained analog data is then transmitted to the color monitor 107 through a display cable, and the image data is displayed on the color monitor 107. Here, if a user

2025 103 104 105 106 107 108 109 110 111 112 113 114

instructs to output the image data stored in the main memory 102 through the color printer 109, the CPU 101 first transfers color reproduction gamut information of the proper color monitor and color reproduction gamut 5 information of the proper color printer from the HDD 105 to the main memory 102, and the CPU 101 further transfers these two kinds of color reproduction gamut information to the color signal conversion device 108. Besides, the CPU 101 instructs the color signal 10 conversion device 108 to perform initialization for data conversion from R (red), G (green) and B (blue) image data into C (cyan), M (magenta), Y (yellow) and K (black) image data. The initialization will be later described in detail. After the initialization ended, 15 the R, G and B image data stored in the main memory 102 are transferred to the color signal conversion device 108 through the PCI bus 114 in response to an instruction from the CPU 101. The color signal conversion device 108 performs color signal conversion to the R, G and B image data on the basis of a result 20 of gamut mapping, and then transmits the C, M, Y and K image data being the converted results to the color printer 109. As a result of such a series of operations, the C, M, Y and K image data are output 25 from the color printer 109.

Fig. 2 is a block diagram showing a structure of the color signal conversion device 108.

In Fig. 2, numeral 201 denotes an LUT (look-up table) creation unit in which respective devices operate according to designated procedures to create an LUT for converting the R, G and B image data into the 5 C, M, Y and K image data. Numeral 202 denotes a RAM (random-access memory) in which the LUT created by the LUT creation unit 201 is stored. Numeral 203 denotes an interpolation device in which the C, M, Y and K image data to be output with respect to the input R, G 10 and B image data are calculated through an interpolation operation using the LUT stored in the RAM 202. Numeral 211 denotes a terminal through which the R, G and B image data stored in the main memory are input in an RGB data format according to a raster scan 15 method, and numeral 212 denotes a terminal through which the C, M, Y and K image data corresponding to the input R, G and B image data are output to the color printer.

Next, the internal structure of the LUT creation 20 unit 201 will be explained. Numeral 209 denotes a terminal through which information representing the printer color reproduction gamut is input, and numeral 210 denotes a terminal through which information representing the monitor color reproduction gamut is 25 input. Numeral 204 denotes a monitor color gamut storage device which stores the input monitor color reproduction gamut information, and numeral 205 denotes

a printer color gamut storage device which stores the input printer color reproduction gamut information. Numeral 206 denotes a mapping parameter calculation device which calculates compression parameters 5 necessary in a later-described color gamut mapping device 207, by referring to the printer color reproduction gamut information and the monitor color reproduction gamut information. Numeral 207 denotes the color gamut mapping device which maps the monitor 10 color reproduction gamut into the printer color reproduction gamut by referring the monitor color reproduction gamut information and the printer color reproduction gamut information. Hereinafter, the result of the mapping is called a mapping color 15 reproduction gamut. Numeral 208 denotes an LUT creation device which creates the LUT for converting the R, G and B image data into the C, M, Y and K image data, by referring to relation between the monitor color reproduction gamut and the mapping color 20 reproduction gamut, the R, G and B image data for outputting a predetermined color on the monitor, and the C, M, Y and K image data for outputting a predetermined color on the printer.

Next, the operation of the LUT creation unit 201 25 will be explained. It should be noted that, although an $L^*a^*b^*$ color space is used as a uniform color system in the mapping operation of the LUT creation unit 201

according to the present embodiment, another kind of uniform color system may be used.

First, the color reproduction gamut information of the color monitor and the color reproduction gamut information of the color printer are transmitted in response to an instruction from the CPU 101. The transmitted color reproduction gamut information of the color monitor is stored as the monitor color reproduction gamut information in the monitor color gamut storage device 204 in the LUT creation unit 201, and the transmitted color reproduction gamut information of the color printer is stored as the printer color reproduction gamut information in the printer color gamut storage device 205 in the LUT creation unit 201. After the transmission of the information ended, it is instructed by the CPU 101 to perform initialization for color signal conversion. If such an instruction is received by the color signal conversion device 108, the internal structure of the LUT creation unit 201 operates as follows. First, the mapping parameter calculation device 206 operates to calculate the various parameters necessary for the color gamut mapping device 207.

After the calculation of the parameters ended, the color gamut mapping device 207 operates to map the monitor color reproduction gamut into the printer color reproduction gamut in the uniform color system. It

should be noted that, in the present embodiment, the color gamut mapping device 207 performs the mapping operation according to a flow chart shown in Fig. 3, and such the mapping operation will be described later.

5 Next, the LUT creation device 208 creates the LUT for converting the R, G and B image data into the C, M, Y and K image data by referring to the mapping color reproduction gamut being the final mapping result, and then writes the created LUT in the RAM 202. After such
10 a series of operations as above ended, the LUT creation device 208 notifies the CPU 101 of the fact that the initialization ended.

15 In the following, the operation of the color gamut mapping device 207 will be explained with reference to the flow chart shown in Fig. 3. It should be noted that, in the explanation of the flow chart in Fig. 3, a consecutive locus by which a certain color and a certain color are connected is called a gradation line.

20 In a step 301, sample points to define the mapping of the color gamut is determined. The determined sample points include surface sample points to define the mapping on the surface of the monitor color reproduction gamut and internal sample points to define the mapping in the monitor color reproduction gamut.

25 In a step 302, with respect to the surface sample points, it is determined where the mapping should be performed within the printer color reproduction gamut.

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Here, it should be noted that the mapping result of the surface sample points is not necessarily located on the surface of the printer color reproduction gamut. In a step 303, with respect to the internal sample points, 5 it is determined where the mapping should be performed within the printer color reproduction gamut. In this case, it should be noted that the mapping is controlled such that the mapping result of the internal sample points is sure to be located inside the printer color 10 reproduction gamut.

In a step 304, a gradation line (called a surface gradation line hereinafter) connecting the predetermined two different surface sample points is defined. Then, in a step 305, with respect to the surface gradation line, it is determined where the mapping should be performed within the printer color reproduction gamut. In this case, it should be noted that the mapping is controlled such that the mapping result of the surface gradation line is sure to be the consecutive locus. Further, it should be noted that the mapping result of the surface gradation line is not necessarily located on the surface of the printer color reproduction gamut.

In a step 306, a gradation line (called an internal gradation line hereinafter) connecting the predetermined two different internal sample points is defined. Then, in a step 307, with respect to the

internal gradation line, it is determined where the mapping should be performed within the printer color reproduction gamut. In this case, it should be noted that the mapping is controlled such that the mapping 5 result of the internal gradation line is sure to be the consecutive locus and to be located inside the printer color reproduction gamut.

Finally, in a step 308, with respect to the color desired to represent the mapping color reproduction 10 gamut, the mapping result of the monitor color reproduction gamut into the mapping color reproduction gamut is calculated on the basis of the surface and internal gradation lines.

In the present embodiment, following two methods 15 are adopted to obtain the mapping result. One is the method of first calculating internal divided ratio of the gradation line for the desired color before the mapping, and then obtaining the mapping result from the gradation line after the mapping in accordance with the 20 calculated internal divided ratio, and the other is the method of first calculating angle ratio on the gradation line for the desired color before the mapping, and then obtaining the mapping result from the gradation line after the mapping in accordance with the 25 calculated angle ratio.

In order to represent the surface gradation line and the internal gradation line, various spline curves

such as a B-Spline curve, a one- or more-dimensional Spline curve, etc., a Bezier curve, and the like can be used.

According to the present embodiment, a proper
5 change rate in a case where color varies according to a certain rule in the color reproduction gamut before the mapping can be preserved, whereby the gradation can be well maintained. Further, according to the present embodiment, since the various spline curves can be used
10 to represent the surface gradation line and the internal gradation line, free and easy control can be performed. Further, since various spline technique and curve fitting technique in a 3D-CAD (three-dimensional computer-aided design) and the like can be applied,
15 extendibility is abundant.

Further, according to the present embodiment, in addition to the mapping from the monitor color reproduction gamut into the printer color reproduction gamut, various applications such as mapping from the
20 printer color reproduction gamut into another different printer color reproduction gamut, mapping from the monitor color reproduction gamut into another different monitor color reproduction gamut, and the like can be performed.

25 In the present embodiment, the restraint condition to preserve the change rate results in the technique of the mapping by "curve". Namely, the locus of the

change of the color in the color reproduction gamut
being the mapping origin is represented by using the
curve, and the mapping is performed such that the
change rate of this curve is maintained, whereby the
5 change rate is preserved.

According to the present invention, the proper
change rate in the case where the color varies
according to the certain rule in the color reproduction
gamut before the mapping can be preserved, whereby the
10 gradation can be well maintained, and the gamut mapping
to absorb the difference in shapes of the monitor color
reproduction gamut and the printer color reproduction
gamut can be performed. Therefore, in case of
15 outputting the image corrected by the gamut mapping, a
problem on sight such as a pseudo contour or the like
can be greatly decreased, and also the images in which
the sights of colors are matched with others can be
obtained.

(Second Embodiment)

20 In the first embodiment, the color gamut mapping
with very high freedom degree is possible. On the
other hand, since the control items extend to be
multiplex, the load for color design becomes heavy.
For example, since there are huge freedom degrees even
25 in only setting the surface sample points and the
internal sample points, to adjust them requires labor.
Thus, in the second embodiment, a method of reducing

the labor in the color design by daring to add limitations to the surface sample points and the internal sample points is proposed.

It should be noted that the second embodiment is obtained by modifying the operation algorithm of the color gamut mapping device 207 in the first embodiment. For this reason, the operation explanation overlapping with the operation explanation in the first embodiment is omitted, and only the operation algorithm of the color gamut mapping device 207 will be explained.

The operation of the color gamut mapping device 207 will be explained with reference to the flow chart shown in Fig. 3. Hereinafter, each step of the flow chart will be described in detail.

To determine the sample points in the step 301 will be described in detail.

In case of determining the surface sample points and the internal sample points, later-described restraint conditions are defined, and sample points distributed on six faces of a red face, a green face, a blue face, a cyan face, a magenta face and an yellow face are thought. Of course, to control the mapping, there is no problem even if a sample point which does not satisfy the later-described restraint conditions and is not distributed on the above six faces exists.

The restraint condition to the sample points distributed on the six faces is not defined in an $L^*a^*b^*$

color space but defined in an RGB color space. The conversion relation between the RGB color space and the L*a*b* color space has been stored in the monitor color gamut storage device 204 storing the monitor color reproduction gamut, and the color gamut mapping device 207 can always use the stored conversion relation. It should be noted that the color reproduction gamut in the RGB color space is defined by $0 \leq R \leq 255$, $0 \leq G \leq 255$, and $0 \leq B \leq 255$.

First, the condition for the surface sample point will be described. Namely, the condition for the sample point is to satisfy any of following 12 conditions.

condition A1) $G = B = 0$, $0 \leq R \leq 255$

condition A2) $0 \leq G = B \leq 255$, $R = 255$

If either one of these two conditions is satisfied, the sample point is located on the red face and on the surface of the monitor color reproduction gamut.

condition A3) $R = B = 0$, $0 \leq G \leq 255$

condition A4) $0 \leq R = B \leq 255$, $G = 255$

If either one of these two conditions is satisfied, the sample point is located on the green face and on the surface of the monitor color reproduction gamut.

condition A5) $R = G = 0$, $0 \leq B \leq 255$

condition A6) $0 \leq R = G \leq 255$, $B = 255$

If either one of these two conditions is satisfied, the sample point is located on the blue face and on the surface of the monitor color reproduction gamut.

5 condition A7) $R = 0, 0 \leq G = B \leq 255$

condition A8) $0 \leq R \leq 255, G = B = 255$

If either one of these two conditions is satisfied, the sample point is located on the cyan face and on the surface of the monitor color reproduction gamut.

10

condition A9) $G = 0, 0 \leq R = B \leq 255$

condition A10) $0 \leq G \leq 255, R = B = 255$

15

If either one of these two conditions is satisfied, the sample point is located on the magenta face and on the surface of the monitor color reproduction gamut.

condition A11) $B = 0, 0 \leq R = G \leq 255$

condition A12) $0 \leq B \leq 255, R = G = 255$

20

If either one of these two conditions is satisfied, the sample point is located on the yellow face and on the surface of the color reproduction gamut.

25

Next, the condition for the internal sample point will be described. Namely, the condition for the internal sample point is to satisfy any of following six conditions.

condition B1) $G = B \leq R, 0 < R < 255$

If this condition is satisfied, the sample point is located on the red face and inside the monitor color reproduction gamut.

condition B2) $R = B \leq G, 0 < G < 255$

5 If this condition is satisfied, the sample point is located on the green face and inside the monitor color reproduction gamut.

condition B3) $R = G \leq B, 0 < B < 255$

10 If this condition is satisfied, the sample point is located on the blue face and inside the monitor color reproduction gamut.

condition B4) $R \leq G = B, 0 < G = B < 255$

15 If this condition is satisfied, the sample point is located on the cyan face and inside the monitor color reproduction gamut.

condition B5) $G \leq R = B, 0 < R = B < 255$

If this condition is satisfied, the sample point is located on the magenta face and inside the monitor color reproduction gamut.

20 condition B6) $B \leq R = G, 0 < R = G < 255$

If this condition is satisfied, the sample point is located on the yellow face and inside the monitor color reproduction gamut.

25 Further, in the mapping calculation of the surface sample points in the step 302, a next restraint condition is newly added. Namely, with respect to the surface sample point which satisfies any one of the

conditions A1, A3, A5, A7, A9 and A11, the mapping is surely performed on the surface of the printer color reproduction gamut. However, with respect to the surface sample point which satisfies any one of the 5 conditions A2, A4, A6, A8, A10 and A12, the mapping might be performed inside the printer color reproduction gamut.

Here, loci of the surface sample point before and after the mapping on the green face is schematically 10 shown in Fig. 4 as an example of the mapping in the step 302. In Fig. 4, the alternate short and long dashed line represents the locus of the surface sample point obtained in case of satisfying either the condition A3 or the condition A4, and the solid line 15 represents the locus obtained in case of mapping the surface sample point. The dotted line represents an example of the locus obtained in the case where all the surface sample points are mapped into the surface of the printer color reproduction gamut.

20 In the following explanation, a chroma-lightness locus (i.e., the locus represented by the alternate short and long dashed line in Fig. 4) of the surface sample point in case of satisfying either the condition A3 or the condition A4 is called a monitor green line. 25 Further, a chroma-lightness locus (i.e., the locus represented by the solid line in Fig. 4) obtained by mapping the surface sample point is called a mapped

green line.

Further, according to the above expression manner, a chroma-lightness locus of the surface sample point in case of satisfying either the condition A1 or A2 is 5 called a monitor red line, a chroma-lightness locus of the surface sample point in case of satisfying either the condition A5 or A6 is called a monitor blue line, a chroma-lightness locus of the surface sample point in case of satisfying either the condition A7 or A8 is 10 called a monitor cyan line, a chroma-lightness locus of the surface sample point in case of satisfying either the condition A9 or A10 is called a monitor magenta line, and a chroma-lightness locus of the surface sample point in case of satisfying either the condition 15 A11 or A12 is called a monitor yellow line. In case of not especially sticking to hue, such the locus is called a monitor line. Further, corresponding chroma-lightness loci obtained by mapping the surface sample point are respectively called a mapped red line, a 20 mapped blue line, a mapped cyan line, a mapped magenta line and a mapped yellow line. In case of not especially sticking to hue, such the locus is called a mapped line.

Next, the process in the step 303 will be 25 explained with reference to a flow chart of Fig. 5.

It should be noted that the present embodiment is directed to the algorithm on the premise that the

mapping to be originally performed on a three-dimensional space has been reduced to the mapping on a two-dimensional space.

In a step 501, a lightness component L_s , a chroma component C_s and a hue component H_s are separated from an internal sample point S . In a step 502, the mapping is performed only for the separated light component L_s , and in a step 503, the mapping is performed only for the separated chroma component C_s .

In the above steps, a boundary of the area to which the internal sample point can be mapped for the red face is called a first intermediate mapped red line, such a boundary for the green face is called a first intermediate mapped green line, such a boundary for the blue face is called a first intermediate mapped blue line, such a boundary for the cyan face is called a first intermediate mapped cyan line, such a boundary for the magenta face is called a first intermediate mapped magenta line, and such a boundary for the yellow face is called a first intermediate mapped yellow line. In case of not especially sticking to hue, such a boundary is called a first intermediate mapped line.

As one example, Fig. 10 schematically shows relation between the monitor green line (the locus represented by the alternate short and long dashed line) and the first intermediate mapped green line (the locus represented by the solid line) on the green face.

In a step 504, in order to adjust the lightness, the mapping of the lightness is again performed as keeping the chroma constant.

In this step, a boundary of the area to which the
5 internal sample point can be mapped for the red face is
called a second intermediate mapped red line, such a
boundary for the green face is called a second
intermediate mapped green line, such a boundary for the
blue face is called a second intermediate mapped blue
10 line, such a boundary for the cyan face is called a
second intermediate mapped cyan line, such a boundary
for the magenta face is called a second intermediate
mapped magenta line, and such a boundary for the yellow
face is called a second intermediate mapped yellow
15 line. In case of not especially sticking to hue, such
a boundary is called a second intermediate mapped line.

In a case where the mapped line has been
previously given, if the first intermediate mapped line
is determined, the locus of the second intermediate
20 mapped line is determined biuniquely based on the
relation between the first intermediate mapped line and
the mapped line. Namely, when only the lightness
component is mapped for the first intermediate mapped
line, the second intermediate mapped line is given.
When only the chroma component is mapped for the second
25 intermediate mapped line, the mapped line is given.
Therefore, if the chroma component of the first

intermediate mapped line is combined with the lightness component of the mapped line, the second intermediate mapped line is given.

The present embodiment is explained on the premise
5 that the mapped line has been previously given.

Here, Fig. 14 schematically shows relation between the first intermediate mapped green line and the second intermediate mapped green line on the green face.

In a step 505, in order to match the final mapping
10 area with the mapped green line, the mapping of the chroma is performed as keeping the lightness constant. By this step, the mapping area of the internal sample points represented by the second intermediate mapped line is mapped into the mapping area represented by the
15 mapped line. Here, Fig. 18 schematically shows relation among the first intermediate mapped green line, the second intermediate mapped green line and the mapped green line on the green face.

In the following, the lightness mapping operation
20 in the step 502 will be explained in detail.

An input/output function is controlled to preserve, for intermediate lightness, such the lightness. In the vicinities of maximum lightness and minimum lightness, the input/output function is
25 controlled to lower the differentiation value of the input/output function, i.e., to increase a compression ratio. Further, in order to prevent that a pseudo

contour or the like appears, the input/output function is controlled such that at least a first differentiation becomes continuous in all the points (i.e., C1 continuousness). Fig. 9 shows an example of 5 the mapping of the lightness component according to the present embodiment. It should be noted that control parameters in this mapping have been previously set by the mapping parameter calculation device 206.

10 In the following, the chroma mapping operation in the step 503 will be explained in detail with reference to a flow chart shown in Fig. 6.

15 In a step 601, a contour chroma compression ratio R_b in hue of the color M being the mapping target is obtained by the mapping parameter calculation device 206. The hue of the color M belongs to any of the red face, the green face, the blue face, the cyan face, the magenta face and the yellow face, and the contour chroma compression ratio R_b is determined for each of these six faces.

20 In a step 602, a color B_m at the boundary of the monitor line in the lightness same as the color M is calculated. Fig. 7 schematically shows the relation between the color M and the color B_m . In Fig. 7, the solid line represents the monitor line, and the dotted line schematically represents how the contour of the monitor line is mapped in the chroma mapping operation of the step 503.

In a step 603, a ratio R is calculated from chroma Cm of the color M and chroma Cbm of the color Bm, as $R = Cm/Cbm$. Next, in a step 604, a chroma input/output function $g(\cdot)$ for chroma mapping is obtained by the 5 mapping parameter calculation device 206.

In a step 605, the chroma mapping is performed by using a following expression, on the basis of the parameters calculated and obtained as above. It should be noted that symbol Cm_{mapped} denotes the chroma after 10 the mapping.

$$Cm_{mapped} = Cbm \times g(R)$$

Here, the chroma input/output function $g(\cdot)$ has following conditions. Namely, the support of $g(\cdot)$ is $[0, 1]$, $g(\cdot)$ increases monotonously, $g(0) = 0$, $g(1) = 15 Rb$, $g(\cdot)$ is at least $C1$ continuousness, $g'(0) = 1$, $g'(1) = \gamma$ ($\gamma > 0$, γ is a constant to control the compression, γ is determined for each hue, and γ varies in inverse proportion to Rb), and $g'(x) \neq 0$ ($0 \leq x \leq 1$).

20 The chroma input/output function $g(\cdot)$ can be shown as a schematic diagram in Fig. 8. Namely, as the chroma becomes lower, the chroma is preserved more. Further, as the chroma becomes higher, the chroma is compressed at a higher compression ratio. Further, 25 since the input/output function is at least the $C1$ continuousness, the change rate of the chroma smoothly varies, whereby it is prevented that the pseudo contour

or the like appears.

By the lightness mapping operation in the step 502 and the chroma mapping operation in the step 503 as described above, the area surrounded by the monitor line is mapped into the area surrounded by the first intermediate mapped line. Fig. 10 shows the state of the mapping on the green face by way of example. In Fig. 10, the alternate short and long dashed line represents the monitor green line and the chroma-lightness loci belonging to the green face in the monitor color reproduction gamut, the solid line represents the first intermediate mapped green line and the mapping result of the chroma-lightness loci, and the dotted line represents the mapped green line.

In the following, the lightness adjustment mapping operation in the step 504 will be explained with reference to a flow chart shown in Fig. 11.

In a step 1101, an upper boundary B_u of the first intermediate mapped line in the chroma same as a color M_1 is calculated. In a step 1102, a lower boundary B_l of the first intermediate mapped line in the chroma same as the color M_1 is calculated. Fig. 12 shows an example of the relation among the color M_1 , the upper boundary B_u and the lower boundary B_l on the green face. In Fig. 12, the solid line represents the first intermediate mapped green line, the alternate short and long dashed line represents the second intermediate

mapped green line, and the dotted line represents the mapped green line.

In a step 1103, an upper boundary Bu_{mapped} of the second intermediate mapped line in the chroma same as the color M1 is calculated, and an upper lightness correction value Ad_u is obtained as $Ad_u = Bu_{\text{mapped}} - Bu$. Fig. 12 schematically shows the relation between the upper lightness correction value Ad_u and the upper boundary Bu . In a step 1104, a lower boundary Bl_{mapped} of the second intermediate mapped line in the chroma same as the color M1 is calculated, and a lower lightness correction value Ad_l is obtained as $Ad_l = Bl_{\text{mapped}} - Bl$. Fig. 12 schematically shows the relation between the lower lightness correction value Ad_l and the lower boundary Bl .

In a step 1105, an input/output function $p(\cdot)$ for mapping of lightness adjustment is given from the above four parameters. In case of giving the input/output function $p(\cdot)$, it is required to satisfy following conditions. Here, symbol L_{Bl} denotes the lightness of lower boundary Bl , symbol L_{Blm} denotes the lightness of the lower boundary Bl_{mapped} , symbol L_{Bu} denotes the lightness of the upper boundary Bu , and symbol L_{Bum} denotes the lightness of the lower boundary Bl_{mapped} .

The above necessary conditions are as follows.

Namely, the support of $p(\cdot)$ is $[L_{Bl}, L_{Bu}]$, $p(\cdot)$ increases monotonously on the support, $p(L_{Bl}) = L_{Blm}$, $p(L_{Bu}) = L_{Bum}$.

5 $p(\cdot)$ is at least C1 continuousness, $p'(L_{B1}) = \alpha$ ($\alpha > 0$,
 α is a constant to control the compression, α is
 determined for each hue according to the lower
 lightness correction value Ad_l ($\alpha \leq 1$ if Ad_l is
 positive, while $\alpha \geq 1$ if Ad_l is negative)), and $p'(L_{Bu})$
 = β ($\beta > 0$, β is a constant to control the compression,
 β is determined for each hue according to the upper
 lightness correction value Ad_u ($\beta \geq 1$ if Ad_u is
 positive, while $\beta \leq 1$ if Ad_u is negative)).

10 The input/output function $p(\cdot)$ is calculated so as
 to satisfy the above conditions. Further, in order to
 preserve the lightness at the intermediate part of the
 support as much as possible, the input/output function
 $p(\cdot)$ is calculated such that a lightness change
 15 quantity decreases as much as possible. Here, Figs.
 13A and 13B show an example of the input/output
 function $p(\cdot)$ in the present embodiment.

20 Finally, in a step 1106, by using the input/output
 function $p(\cdot)$ obtained in the step 1105, lightness
 Lm_{mapped} after the mapping of the color $M1$ is obtained
 with respect to lightness Lm before the mapping, as
 $Lm_{mapped} = p(Lm)$. Thus, the mapping to adjust the
 lightness is performed.

25 By the lightness adjustment mapping operation in
 the step 504, the area surrounded by the first
 intermediate mapped line is mapped into the area
 surrounded by the second intermediate mapped line.

Fig. 14 shows an example of the mapping on the green face. In Fig. 14, the alternate short and long dashed line represents the first intermediate mapped green line and the mapping result of the chroma-lightness loci explained in the step 502, the solid line represents the second intermediate mapped green line and the result obtained by the lightness mapping to the mapping result of the chroma-lightness loci, and the dotted line represents the mapped green line.

In the following, the chroma mapping operation in the step 505 will be explained in detail with reference to a flow chart shown in Fig. 15.

In a step 1501, in the hue of a color M2 being the mapping target, a boundary (color) Bp of the mapped line in the lightness same as the color M2 is calculated. In a step 1502, a boundary (color) Bi of the second intermediate mapped line in the lightness same as the color M2 is calculated. Fig. 16 schematically shows the relation among the color M2, the color Bp and the color Bi on the green face. In Fig. 16, the solid line represents the second intermediate mapped green line, and the dotted line represents the mapped green line.

In a step 1503, an input/output function $q(\cdot)$ for mapping of color gamut correction is given from the color Bp and the color Bi calculated in the above steps. Here, in a case where symbol c_p denotes chroma

of the color B_p and symbol c_i denotes chroma of the color B_i , the input/output function $q(\cdot)$ is required to satisfy following conditions.

Namely, the support of $q(\cdot)$ is $[0, c_i]$, $q(0) = 0$,
5 $q(c_i) = c_p$, $q'(0) = 1$, $q'(c_i) = \gamma$ ($\gamma > 0$), and $q'(x) \neq 0$
($0 \leq x \leq c_i$). The symbol γ is the value to control
enlargement ratio/compression ratio of the chroma
correction in the vicinity of the maximum chroma, and
this value is automatically determined. However, in
10 case of $c_i > c_p$, $\gamma < 1$ is given, and the mapping by the
input/output function $q(\cdot)$ is the compression
operation. On the other hand, in case of $c_i \leq c_p$, $\gamma \geq 1$
is given, and the mapping by the input/output function
15 $q(\cdot)$ is the expansion (or decompression) operation.
Fig. 17A shows an example of the input/output function
 $q(\cdot)$ in case of $c_i \leq c_p$ (i.e., the expansion operation),
and Fig. 17B shows an example of the input/output
function $q(\cdot)$ in case of $c_i > c_p$ (i.e., the compression
operation).

20 In a step 1504, the chroma of the color M_2 is
converted by using the input/output function $q(\cdot)$
obtained in the step 1503. If symbol c_{org} denotes
chroma of the color M_2 and symbol c_{mod} denotes chroma of
the color M_2 after the conversion, $c_{mod} = q(c_{org})$ is
25 given.

By the chroma mapping operation in the step 504,
the area surrounded by the second intermediate mapped

line is mapped into the area surrounded by the mapped line. Fig. 18 shows an example of the mapping on the green face. In Fig. 18, the alternate short and long dashed line represents the second intermediate mapped green line and the lightness mapping result of the chroma-lightness loci explained in the step 503, and the solid line represents the mapped green line and the result obtained by the chroma mapping to the lightness mapping result of the chroma-lightness loci.

Finally, in a step 506, the hue is appropriately adjusted on the basis of the information obtained by the mapping parameter calculation device 206.

As above, the mapping of the internal sample points in the step 303 was described in detail. In the step 303 of the present embodiment, the algorithm on the premise that the mapping to be originally performed on the three-dimensional space has been reduced to the mapping on the two-dimensional space was explained. However, it is of course possible to perform the mapping on the three-dimensional space as it is.

In the following, an example of the method to define the surface gradation line in the step 304 will be described with reference to Fig. 19.

Fig. 19 shows a state that the surface gradation lines is defined in a case where the number of surface sample points belonging to each face is the identical. Here, a gradation line L_i in Fig. 22 represents the

surface gradation line connecting the surface sample point on the red face and the surface sample point on the yellow face with each other. Symbol R_i denotes a surface sample point on the red face, and an index i is given to this surface sample point in the order of higher lightness. Symbol Y_i denotes a surface sample point on the yellow face, and an index i is given to this surface sample point in the order of higher lightness. As apparent from the drawings, in the present embodiment, the sample points having the identical index number are connected to define the surface gradation line. Further, the surface gradation line has following R , G and B values.

$$\begin{aligned} R &= (1-t)R_{ri} + tY_{yi} \\ 15 \quad G &= (1-t)G_{ri} + tG_{yi} \\ B &= (1-t)B_{ri} + tB_{yi} \end{aligned}$$

Here, symbols R , G and B respectively denote the R , G and B values of the surface gradation line, symbols R_{ri} , G_{ri} and B_{ri} respectively denote the R , G and B values of the sample point R_i , symbols R_{yi} , G_{yi} and B_{yi} respectively denote the R , G and B values of the sample point Y_i , and $0 \leq t \leq 1$.

Namely, the surface gradation line is obtained by representing in the $L^*a^*b^*$ color space the line connecting the surface sample points on the RGB color space.

However, in addition to the above expression of

the present embodiment, the surface gradation line can be represented in various definition methods. Thus, any inconvenience does not occur even if the definition method different from that shown in the present 5 embodiment is used. Further, any inconvenience does not occur even if the number of surface sample points belonging to each face is not the identical.

In the mapping of the surface gradation line in the step 305, the surface gradation line of Fig. 19 is, 10 e.g., shown in Fig. 20. Further, as described also in the first embodiment, it should be noted that the mapping result of the surface gradation line is not necessarily located on the surface of the printer color reproduction gamut.

15 In the following, an example of the method to define the internal gradation line in the step 306 will be described with reference to Fig. 21.

Fig. 21, a gradation line Lin_{ij} represents the internal gradation line connecting an internal sample 20 point Rin_i on the red face and an internal sample point Yin_j on the yellow face with each other. Here, the internal gradation line has following R, G and B values.

$$\begin{aligned} R &= (1-t)\text{Rri} + t\text{Ryj} \\ 25 \quad G &= (1-t)\text{Gri} + t\text{Gyj} \\ B &= (1-t)\text{Bri} + t\text{Byj} \end{aligned}$$

Here, symbols R, G and B respectively denote the

R, G and B values of the internal gradation line, symbols R_{ri}, G_{ri} and B_{ri} respectively denote the R, G and B values of the sample point R_{in_i}, symbols R_{yj}, G_{yj} and B_{yj} respectively denote the R, G and B values of the sample point Y_{in_j}, and 0 ≤ t ≤ 1.

Namely, as well as the surface gradation line, the internal gradation line is obtained by representing in the L^{*}a^{*}b^{*} color space the line connecting the surface sample points on the RGB color space.

10 Although the mapping of the internal gradation line in the step 307 is influenced from either one or both the surface gradation line and the adjacent internal gradation line, such the influence is eased in proportion to the distance between the influenced 15 surface gradation line and the influenced internal gradation line. For example, the internal gradation lines shown in Fig. 21 are mapped as shown in Fig. 22.

Figs. 23 and 24 show an example of gradation line control based on a control point. Concretely, Fig. 23 20 shows that a control point Cnt is determined on the gradation line Lin_55, and Fig. 24 shows the coordinates at which the control point Cnt of Fig. 23 is mapped. Thus, the mapping of the internal gradation line Lin_55 varies according to the mapping of the 25 control point Cnt. Also, the adjacent internal gradation line varies due to influence of the mapping variation of the internal gradation line Lin_55, but

such the influence is eased in proportion to the distance from the internal gradation line Lin_55. In the present embodiment, the internal gradation line is controlled to be passed through the control point, but 5 the internal gradation line is not necessarily passed through the control point in such as case as the B-Spline curve is used.

As well as the first embodiment, it should be noted that the mapping is controlled such that the 10 mapping result of the surface sample points is sure to be located inside the printer color reproduction gamut.

As described above, according to the present embodiment, since the gamut mapping is controlled on the basis of the six hues of primary colors, it is 15 possible to perform intuitive control.

Further, according to the present embodiment, since the prior art is applied to the mapping of the six hue faces, it is possible to use conventional know-how and also take adjustment with the conventional 20 gamut mapping.

(Third Embodiment)

In the third embodiment, how to take the surface sample points and the internal sample points in the second embodiment is devised, and also how to take the 25 surface gradation line and the internal gradation line in the second embodiment is devised, whereby the labor in the color design is further reduced, and the control

is made further easy to be grasped intuitively.

It should be noted that the third embodiment is obtained by modifying the surface sample points and the internal sample points in the operation algorithm of 5 the color gamut mapping device 207 in the second embodiment. For this reason, the parts overlapping with the parts in the second embodiment are omitted, and only the different parts will be described.

In the following, how to determined the sample 10 point in the step 301 of the flow chart shown in Fig. 3 will be described in detail.

In the present embodiment, how to determine the surface and internal sample points distributed on the six faces, i.e., red, green, blue, cyan, magenta and 15 yellow faces, will be explained. Incidentally, of course, there is no problem even if a sample point which is not distributed on any of the above six faces (i.e., not satisfying any of the conditions A1 to A12 and B1 to B6 in the second embodiment and later- 20 described conditions) exists.

In the present embodiment, the sample point is determined not in the $L^*a^*b^*$ color space but in the RGB color space. Here, as to R, G and B values capable of being taken at the sample point, it is defined to 25 determine the R, G and B values in the same discrete step. Namely, as each of the R, G and B values, it is defined to take any of discrete values shown in Fig.

25. Further, the surface sample point satisfies any of the 12 conditions A1 to A12, and the internal sample point satisfies any of the six conditions B1 to B6.

Fig. 26 shows the distributions of the surface sample points and the internal sample points on the RGB color space, by using the red face and the cyan face as examples. Concretely, Fig. 26 shows the sectional plane which is obtained by sectioning the color reproduction gamut on the RGB color space through three (white, red and black) points. In Fig. 26, the upper left point (255, 255, 255) represents white, and lower right point (0, 0, 0) represents black. The dotted line represents a gray axis which varies from the white point (255, 255, 255) to the black point (0, 0, 0) on the (R, G, B) coordinates. Symbol R_i denotes a surface sample point on the red face, symbol C_i denotes a surface sample point on the cyan face, and an index i is given to such the surface sample point in the order of higher lightness. Further, symbol R_{in_i} denotes an internal sample point on the red face, and symbol C_{in_j} denotes an internal sample point on the cyan face. The index number rule in the internal sample points is as follows.

First, with respect to the internal sample points having the maximum hue component on the hue face in question, the index numbers are sequentially given to these points in the order of higher lightness sample

points. Namely, on the red face, in the internal sample points of which the red components are given as d_1 , the index numbers are sequentially given to these points in the order of higher lightness sample points.

5 Further, on the cyan face, in the internal sample
points of which the green components and the blue
components are given as d_1 , the index numbers are
sequentially given to these points in the order of
higher lightness sample points.

10 Subsequently, with respect to the internal sample
points having the large hue components, the index
numbers are sequentially given to these points in the order of higher lightness sample points. Namely, on
the red face, in the internal sample points of which
15 the red components are given as d_2 , the index numbers
are sequentially given to these points in the order of higher lightness sample points. Further, on the cyan
face, in the internal sample points of which the green
components and the blue components are given as d_2 , the
20 index numbers are sequentially given to these points in the order of higher lightness sample points. After
then, the index numbers are given to all the internal
sample points in the same manner as above, whereby the
distributions as shown in Fig. 26 can be obtained.
25 Besides, on the green, blue, magenta and yellow faces,
the index numbers are given to the internal sample
points in the same manner as above.

In the following, the method to define the surface gradation line in the step 304 will be explained.

In the present embodiment, the surface gradation line is defined by connecting, with a line on the RGB color space, the surface sample points of which the index numbers are the identical respectively on the adjacent hue faces. For example, the surface gradation line between the red face and the yellow face has following R, G and B values.

10
$$R = (1-t)R_{ri} + tR_{yi}$$

$$G = (1-t)G_{ri} + tG_{yi}$$

$$B = (1-t)B_{ri} + tB_{yi}$$

Here, symbols R, G and B respectively denote the R, G and B values of the surface gradation line, symbols R_{ri} , G_{ri} and B_{ri} respectively denote the R, G and B values of the sample point R_i , symbols R_{yi} , G_{yi} and B_{yi} respectively denote the R, G and B values of the sample point Y_i , and $0 \leq t \leq 1$.

20 In the following, the method to define the internal gradation line in the step 306 will be explained.

In the present embodiment, the internal gradation line is defined by connecting, with a line on the RGB color space, the internal sample points of which the index numbers are the identical respectively on the adjacent hue faces. For example, the internal gradation line between the red face and the yellow face

has following R, G and B values.

$$R = (1-t)Rri + tRyi$$

$$G = (1-t)Gri + tGyi$$

$$B = (1-t)Bri + tByi$$

5 Here, symbols R, G and B respectively denote the R, G and B values of the internal gradation line, symbols R_{ri}, G_{ri} and B_{ri} respectively denote the R, G and B values of the sample point R_{in_i}, symbols R_{yi}, G_{yi} and B_{yi} respectively denote the R, G and B values 10 of the sample point Y_{in_i}, and 0 ≤ t ≤ 1.

According to the present embodiment, since how to take the sample points and the gradation lines are devised, the mapping control is made further easy to be grasped intuitively.

15 (Other Embodiments)

The present invention also includes a case of supplying a program code of software for achieving the functions of the above embodiments to a computer (CPU or MPU) in an apparatus or a system connected to 20 various devices to operate these devices to achieve the functions of the above embodiments, and causing the computer in the apparatus or the system to operate these devices according to the supplied program codes.

In this case, the program code of software 25 achieves the functions of the above embodiments, whereby the program code itself and a means such as a storage medium for storing the program code constitute

the present invention.

As the storage medium for storing the program code, e.g., a floppy disk, a hard disk, an optical disk, a magneto-optical disk, a CD-ROM, a magnetic tape, a non-volatile memory card, a ROM or the like can 5 be used.

It is needless to say that the program code is included in the embodiments of the present invention not only in the case where the functions of the above 10 embodiments are achieved by executing the supplied program code with the computer, but also in a case where the program code cooperates with an OS (operating system) running on the computer or other application software to achieve the functions of the above 15 embodiments.

Further, it is needless to say that the present invention includes a case where the supplied program code is stored in a memory provided in a function expansion board inserted in the computer or a function expansion unit connected to the computer, thereafter, on the basis of an instruction of the program code, a 20 CPU or the like provided in the function expansion board or the function expansion unit executes a part or all of actual processes, and thus the functions of the above 25 embodiments are achieved by such the processes.

The present invention can be modified in various manner within the scope of the following claims.